# COST AND PERFORMANCE REPORT

## EXECUTIVE SUMMARY

This report presents cost and performance data for a slurry-phase bioremediation application at the French Limited Superfund Site (French Ltd.) in Crosby, Texas. This project is notable for being a large, full-scale application of slurry-phase bioremediation at a Superfund site. In addition, an innovative system (the MixFlo system) was used for aeration that minimized air emissions while supplying adequate oxygen to the biomass.

The French Ltd. site is a former permitted industrial waste disposal facility, where an estimated 70 million gallons of wastes from area petrochemical companies were disposed of on site between 1966 and 1971, primarily in an unlined lagoon. Contaminants of concern included polynuclear aromatic hydrocarbons, chlorinated organics, and metals.

In 1983, the Potentially Responsible Parties (PRPs) formed the French Limited Task Group (FLTG) to lead the remediation at the site. A Record of Decision (ROD) was signed on March 24, 1988. The ROD specified bioremediation for remediation of the lagoon. A slurry-phase bioremediation process was operated from January 1992 through November 1993 to remediate approximately 300,000 tons of tar-like sludge and subsoil from the lagoon. The slurry-phase bioremediation process achieved the specified soil cleanup goals for the five target contaminants (benzo(a)pyrene, total PCBs, vinyl chloride, arsenic, and benzene) within 11 months of treatment.

Costs for the slurry-phase bioremediation system including technology development, project management, EPA oversight, and backfill of the lagoon were approximately $49,000,000. Approximately $26,900,000 in costs were for activities directly associated with treatment, which corresponds to $90/ton for treatment of 300,000 tons of soil and sludge.

## SITE INFORMATION

### Identifying Information

**Site Information:** French Limited Superfund Site
Crosby, Texas
**CERCLIS #** TXD980514814
**ROD Date:** 24 March 1988

### Treatment Application

**Type of Action:** Remedial
**Treatability Study Associated With Application?** Yes (See Appendix A)
**EPA SITE Program Test Associated With Application?** No
**Period of Operation:** January 1992-November 1993
**Quantity of Material Treated During Application:** 300,000 tons of soil and sludge; estimated as 70,000 tons of tar-like sludge and 230,000 tons of subsoil, determined by borings of the lagoon bottom.

### Background

**Historical Activity that Generated Contamination at the Site:** Industrial Waste Disposal

**Corresponding SIC Code:** 4953E (Waste management-refuse systems; sand and gravel pit disposal)

**Waste Management Practice that Contributed to Contamination:** Disposal Pit

**Site History:** The French Limited Superfund Site (French Ltd.), a former industrial waste storage and disposal facility, is a 22.5-acre site located in Crosby, Texas, as shown in Figure 1. Between 1966 and 1971, approxi-

# SITE INFORMATION (CONT.)

## Background (cont.)

mately 70 million gallons of industrial wastes from area petrochemical companies were disposed of at the French Ltd. site. These wastes included tank bottoms, pickling acids, and off-specification product from refineries and petrochemical plants. Most of this waste was deposited in an unlined, 7.3-acre lagoon. Wastes were also processed in tanks and burned.

The lagoon was an abandoned sand pit which had filled with water to depths of 20 to 25 feet. The primary contaminants found in the lagoon were polynuclear aromatic hydrocarbons, halogenated semivolatiles, halogenated volatiles, nonhalogenated volatiles, metals, and nonmetallic elements. The lagoon wastes were concentrated in a layer of tar-like sludge approximately 4 feet thick and a 5-6 foot layer of subsoil. [1, 35, 37, 39]

The site is located within the 100-year floodplain of the San Jacinto River and is susceptible to periodic flooding. In May of 1979, a flood occurred and breached the earthen dike which surrounded the lagoon. As a result, contaminated sludges were washed out of the lagoon and into an adjacent slough. In 1982, EPA repaired the dike and pumped the contaminated sludge from the slough back into the lagoon. [1, 9]

EPA identified approximately 90 companies as Potentially Responsible Parties (PRPs), and, in 1983, the PRPs formed the French Limited Task Group (FLTG). In 1984, FLTG agreed to perform the cleanup. [1, 8, 9]

EPA conducted a Remedial Investigation (RI) at the site in 1983, and the FLTG conducted a field investigation and a second RI in 1986. Selection of a remedy for the lagoon was based on the results of the 1983 and 1986 investigations and a Feasibility Study (FS). EPA initially proposed incineration as the remedial technology for the tar-like sludge and affected subsoil at an estimated cost of $75 to $125 million. FLTG then investigated other more cost-effective alternatives. In 1987, FLTG conducted a pilot-scale bioremediation treatability study in a 0.6-acre section of the lagoon (see Appendix A). As a result of the

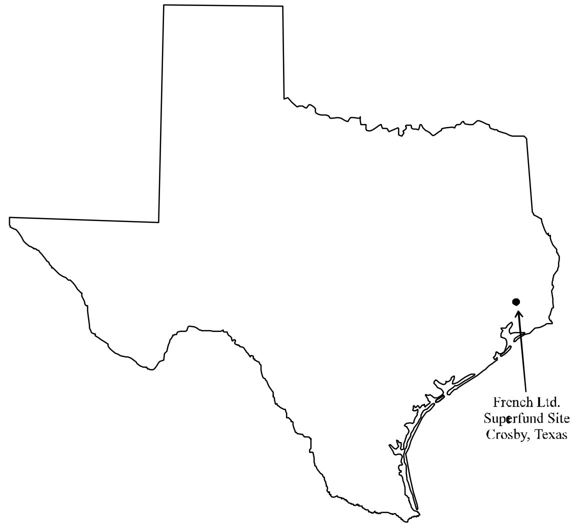


*Figure 1. Site Location*

study, a 1988 ROD replaced incineration with in-situ biodegradation for remediation of the site. [1, 8]

**Regulatory Context:** The ROD specified risk-based quantitative cleanup goals for five types of contaminants on the bottom of the lagoon at the French Ltd. site, as described below under cleanup goals and standards. The ROD also provided specifications for groundwater recovery and treatment. [1]

**Remedy Selection [1]:** The following remedial action alternatives were considered for the French Ltd. site:

- On-site incineration of tar-like sludge and contaminated subsoil;
- On-site incineration of tar-like sludge and chemical fixation of contaminated subsoil in-place;
- Encapsulation of contaminants by slurry walls and a multilayered cap;
- No action; and
- Biological treatment of tar-like sludge and contaminated subsoil.

Biological treatment of sludges and contaminated subsoils was selected because it was believed to be capable of meeting the cleanup goals in a reasonable period of time and at a lower cost than incineration.

# SITE INFORMATION (CONT.)

## Background (cont.)

The ROD indicated that the probability of bioremediation failing was less than for other options. However, if bioremediation failed, the ROD discussed the use of incineration as a backup.

## Site Logistics/Contacts

**Site Management:** PRP Lead

**Oversight:** EPA

**Remedial Project Manager:**
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**Treatment System Vendors:**
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Mr. Gary Storms (Subcontractor)
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Waste Management
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(203) 837-2174

# MATRIX DESCRIPTION

## Matrix Identification

**Type of Matrix processed through the treatment system:** Tar-like sludge and subsoil (in situ - within lagoon)

## Contaminant Characterization [1]

**Primary Contaminant Groups:** Polynuclear aromatic hydrocarbons; halogenated semivolatiles; halogenated volatiles; nonhalogenated volatiles; and nonmetallic elements.

The soil and tar-like sludge in the lagoon contained a variety of organics, metals, and PCBs. The specific types and concentrations of constituents, as identified in the ROD, included:

- PCBs up to 616 mg/kg;
- Volatile organics up to 400 mg/kg for an individual contaminant;
- Pentachlorophenol up to 750 mg/kg;
- Semivolatiles up to 5,000 mg/kg for an individual contaminant; and
- Metals up to 5,000 mg/kg for an individual metal.

Concentrations of specific contaminants in the soil and sludge are presented in the Treatment Performance Data section of this report.

# MATRIX DESCRIPTION (CONT.)

## Matrix Characteristics Affecting Treatment Cost or Performance

Listed below in Table 1 are the major matrix characteristics affecting cost or performance for this technology, and the values measured for each.

The tar-like sludge was aromatic and oily, and consisted of a mixture of petrochemical sludges, kiln dust, and tars (primarily styrene and soils). It was a thick, viscous, oily, black layer about 4 feet thick that covered the bottom of the lagoon. The subsoils varied from fine grained silts to coarse sand. [38, 39]

*Table 1. Matrix Classification [38,39]*

| Parameter | Value | Measurement Procedure |
|---|---|---|
| Soil Classification | See discussion above | -- |
| Clay Content and/or Particle Size Distribution | See discussion above | -- |

# TREATMENT SYSTEM DESCRIPTION

## Primary Treatment Technology Type

Slurry-Phase Bioremediation

## Supplemental Treatment Technology Type

Pretreatment (solids) - mixing

## Slurry-Phase Bioremediation System Description and Operation

The slurry-phase bioremediation system used at French Ltd. stimulated the indigenous microorganisms with aeration, pH control, and nutrients to biologically oxidize the organic waste materials. The tar-like sludge was sheared and introduced into the mixed liquor using open-faced centrifugal pumps mounted on articulated arms. The subsoil was sheared and introduced into the mixed liquor using conventional swinging ladder cutter head dredges. Controlled shearing was a key factor in controlling the growth of biomass. Biomass growth was also controlled by controlling the level of dissolved oxygen and pH. [9, 35]

The tar-like sludge and subsoils were treated separately. If the soils and sludge had been mixed together, the sludge would have coated the soil particles, and the mixture would have had a greater specific gravity and settled more rapidly, thus reducing treatment effectiveness. Treating the sludge separately kept the sludge from coating the soil particles and maximized the surface area available for treatment. [39]

### System Description

As shown in Figure 2, the lagoon was divided into two treatment cells, Cell E and Cell F, of approximately equal volume. The two treatment cells were created by installing a sheet pile wall across the lagoon in a north-south direction so there would be equal treatment media volume in each of the two cells. This configuration allowed for the sequential remediation of the western cell (Cell E) and the eastern cell (Cell F). Additional benefits of the sequential remediation approach were to limit air emissions during the remediation; reduce the amount of capital equipment that had to be purchased; and allow for process improvements over the duration of the remediation. [9]

# TREATMENT SYSTEM DESCRIPTION (CONT.)

## Slurry-Phase Bioremediation System Description and Operation (cont.)

The treatment cells were designed to hold a total mixed liquor volume of 34.0 million gallons (17.0 million gallons in each treatment cell), and to maintain a minimum dissolved oxygen (DO) concentration of 2.0 mg/L in the mixed liquor. Based on the results of the treatability study (see Appendix A), an oxygen uptake rate (OUR) of 0.30 mg/L/minute was chosen as the design basis for aeration supply. The oxygen requirements were determined by multiplying the OUR by the total mixed liquor volume. Oxygen requirements for each cell were determined to be approximately 2,500 pounds/hour. [9]

The main components of the bioremediation process, as shown in Figures 3 and 4, included a MixFlo aeration system, a liquid oxygen supply system, a chemical feed system, and dredging and mixing equipment. A description of the MixFlo Aeration System, sludge and subsoil mixing, chemical addition, and residuals management is presented below.

### MixFlo Aeration System

According to the vendor, the FLTG chose a pure oxygen system rather than an air-based aeration system to lower air emissions during site remediation. Greater amounts of organic air emissions are released from air-based aeration systems because larger amounts of air are required to achieve a specific dissolved oxygen content. The MixFlo system has higher transfer efficiencies than air-based aeration systems (90% as opposed to 30%) and uses high purity oxygen (90% or greater). This combination of higher transfer efficiency and high purity oxygen reduces offgases and air emissions from the treatment process. [35]

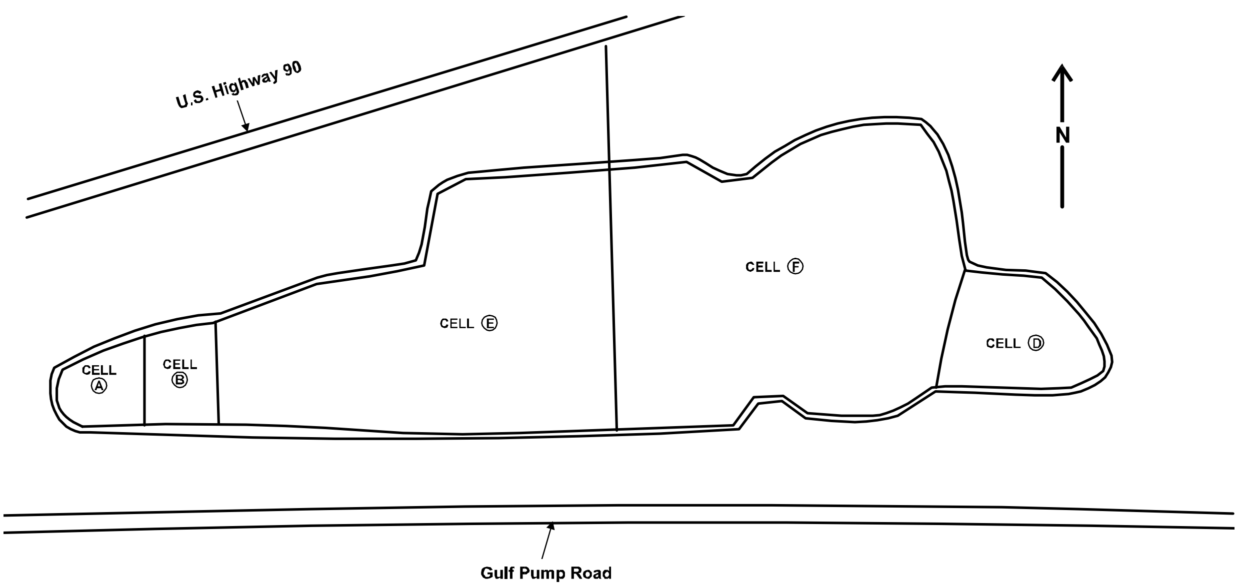


*Figure 2. French Ltd. Lagoon and Bioremediation Treatment Cell Configuration [9]*

# TREATMENT SYSTEM DESCRIPTION (CONT.)

## Slurry-Phase Bioremediation System Description and Operation (cont.)

The MixFlo aeration system used at French Ltd. dissolves oxygen in a two-stage process, as shown in Figure 3. In the first stage, water is pumped from the treatment area and pressurized. Pure oxygen is then injected into the water. The resulting two-phase mixture passes through a pipeline contractor where approximately 60% of the injected oxygen dissolves. In the second stage, the oxygen/water mixture is reinjected into the treatment area using a liquid/liquid eductor. The eductor dissipates the pumping energy in the oxygen/water mixture by ingesting unoxygenated water from the treatment area, mixing it with oxygenated water, and then discharging the overall mixture back into the treatment area, dissolving 75% of the remaining oxygen. [9]

At French Ltd., oxygen was injected in eight pipeline contactors into the mixed liquor at enhanced pressure. The mixed liquor was pressurized by pumps located on two pontoons. The pipeline contactors each supplied three eductors. The circulation flow pattern in the treatment cell established by the eductors' discharge was supplemented by three raft-mounted self-powered circulation mixers. [9]

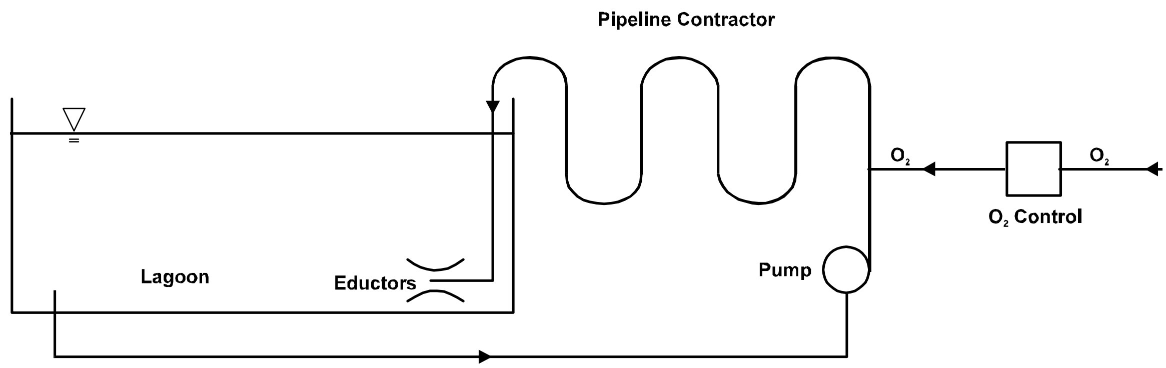


*Figure 3. Schematic Diagram of Mixflow System (adapted from [41])*

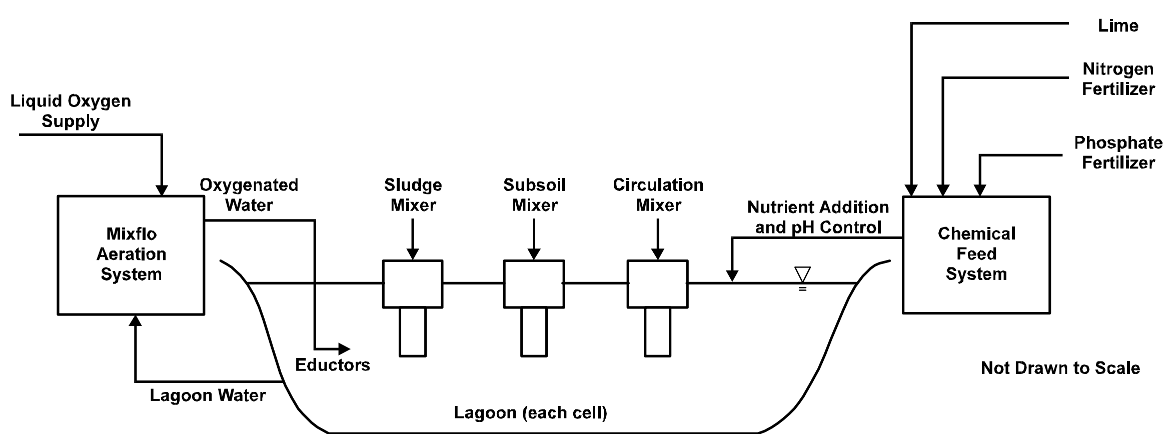


*Figure 4. French Ltd. Lagoon Treatment Process Flow Diagram (adapted from [9])*

## TREATMENT SYSTEM DESCRIPTION (CONT.)

### Slurry-Phase Bioremediation System Description and Operation (cont.)

Oxygen was distributed to the entire volume of mixed liquor in the treatment cell by creating a dual circulation pattern that moved mixed liquor past and through the MixFlo eductors to pick up oxygen, and circulated it around the lagoon where oxygen was consumed in the bioremediation process. [9]

The design of the MixFlo system was based on the following criteria [9]:

- Capacity = 60,000 gpm;
- Motor Power = 3,400 hp;
- Oxygen Transfer Efficiency $\geq$90%;
- Temperature = 40°C;
- Oxygen Requirement = 2,500 lbs/hr;
- Liquid Depth = 10 feet;
- Pump Efficiency = 75%; and
- Saturation Oxygen Concentration (C) = 0.9 x $C_{40°C}$ (tap water) = 27.5 ppm

**Sludge and Soil Mixing**

As described above, different equipment was used for dredging and mixing the tar-like sludges and subsoil. Four sludge mixers provided the shear mixing of sludges necessary to achieve biological treatment of those solid materials. The centrifugal pump selected for use on the sludge mixers had a capacity of 1,250 gallons per minute. [9] Four hydraulic subsoil mixers provided the shear mixing of lagoon bottom subsoils necessary to achieve biological treatment of the waste constituents adsorbed onto these solid materials. Maximum water depth was approximately 25 feet. [9]

**Chemical Addition**

Simple batch systems for chemical addition were used to control the pH and nutrient chemistry of the mixed liquor during treatment. A 35% solution of hydrated lime was diluted on site to 15% concentration by adding water. To offset nutrient losses, nitrogen was added as hydrated urea (46% nitrogen by weight) and phosphorus was added as liquid ammonium phosphate. The system was designed to add batches of up to 1,500 gallons of chemicals to the lagoon at several locations. [9]

**Residuals Management**

After verification that soil and sludge cleanup objectives had been achieved, reverse osmosis was used to treat the surface water in the lagoon. Approximately 40 million gallons of surface water from the lagoon were processed through the reverse osmosis system and discharged to the San Jacinto River. As the lagoon was dewatered, it was backfilled with clean soil. Residual solids were stabilized by mixing with pebble lime in the ratio of five parts solids to one part pebble lime. The site was then planted with grass and native vegetation and contoured to drain away from the lagoon. [34]

# TREATMENT SYSTEM DESCRIPTION (CONT.)

## Operating Parameters Affecting Treatment Cost or Performance

Listed below in Table 2 are the major operating parameters affecting cost or performance for this technology and the values measured for each. System throughput and hydrocarbon degradation are described under system description and treatment performance data, respectively.

*Table 2. Operating Parameters [10-33]*

| Parameter | Value | Measurement Procedure |
|---|---|---|
| Air Flow Rate | 2,500 lbs/hr oxygen | — |
| Dredging Hours | 358 to 1,669 hrs/month | — |
| Mixing Hours | 1,164 to 2,052 hrs/month | — |
| Moisture Content | 70% to 95% | Not Available |
| pH | 6.6 to 8.5 | Not Available |
| Residence Time | 11 months (Cell F),<br>10 months (Cell E) | Not Available |
| Temperature | 71.6 to 98.6° F | Not Available |
| Microbial Plate Count | $10^5$ to $10^7$ CFU/ml | Not Available |
| Oxygen Uptake Rate | 0.9 to 30 mg/L/hr | Not Available |
| Dissolved Oxygen Content | 0.5 to 4.0 mg/L | Not Available |
| HMB Catalyst Activity | 0.4 to 50 units | Not Available |
| Nutrient Nitrogen Content | 0.05 mg/L | Not Available |
| Nutrient Phosphorus Content | 0.05 to 10 mg/L | Not Available |

## Timeline

A timeline for this application is provided in Table 3.

*Table 3. Timeline [1, 9]*

| Start Date | End Date | Activity |
|---|---|---|
| — | 10/83 | Site added to the National Priorities List |
| 4/87 | 4/88 | Biological treatment pilot study conducted on site in a 0.5-acre cell |
| — | 3/88 | ROD signed |
| — | 3/90 | Remedial Action Plan prepared |
| 1/91 | 6/91 | Remedial Design prepared |
| 7/91 | 12/91 | Cleanup facility construction completed |
| 1/92 | 11/92 | Bioremediation of Cell E |
| 11/92 | 12/92 | Transfer of bioremediation equipment to Cell F |
| 1/93 | 11/93 | Bioremediation of Cell F |
| 6/93 | 1/94 | Post-treatment care and backfill of Cell E with clean soil |
| 12/93 | 3/94 | Demobilization of treatment equipment from Cell F |
| 2/94 | 11/94 | Post-treatment care and backfill of Cell F with clean soil |

# TREATMENT SYSTEM PERFORMANCE

## Cleanup Goals/Standards

The ROD specified maximum allowable concentrations for five contaminants in lagoon subsoils and sludges at the French Ltd. site. [1]

These contaminants, listed in Table 4, were specified in the ROD as indicator compounds and the cleanup goals shown above were developed based on the results from a risk assessment using a 1 x $10^{-5}$ excess lifetime cancer risk factor. Bioremediation was required until analytical results for all sampling points (nodes) were in compliance with site remediation cleanup goals for two consecutive sampling events. Each sample from every composited node sample was required to meet the cleanup goals. [1, 9]

In addition, the ROD specified an action level for total VOCs in ambient air of 11 ppm for 5 minutes at any time during treatment. The action level applied to the ambient air at the site boundary for the 35 VOCs listed in Table 5. [9]

*Table 4. Cleanup Goals for Soils and Sludges [1]*

| Contaminant | Maximum Allowable Concentration (mg/kg) |
|---|---|
| Benzo(a)pyrene | 9 |
| Total PCBs | 23 |
| Vinyl Chloride | 43 |
| Arsenic | 7 |
| Benzene | 14 |

*Table 5. VOCs Required to be Measured in Ambient Air [9]*

| | |
|---|---|
| Acetone | 1,1-Dichloroethane |
| Benzene | 1,2-Dichloroethane |
| Bromodichloromethane | Trans-1,2-Dichloroethene |
| Bromoform | Ethylbenzene |
| Bromomethane | 2-Hexanone |
| 2-Butanone | Methylene chloride |
| Carbon disulfide | 4-Methyl-2-pentanone |
| Carbon tetrachloroide | Styrene |
| Chlorobenzene | Tetrachloroethene |
| Chloroethane | 1,1,2,2-Tetrachloroethane |
| 2-Chloroethylvinylether | Toluene |
| Chloroform | Total Xylenes |
| Chloromethane | 1,1,1-Trichloroethane |
| Dibromochloromethane | 1,1,2-Trichloroethane |
| 1,2-Dichloropropane | Trichloroethene |
| cis-1,3-Dichloropropene | Vinyl acetate |
| Trans-1,3-Dichloropropene | Vinyl Chloride |
| 1,1-Dichloroethene | |

# TREATMENT SYSTEM PERFORMANCE (CONT.)

## Treatment Performance Data

Treatment performance was monitored using subsoil and sludge samples and mixed liquor samples. To assess compliance with cleanup goals, subsoil and sludge samples were collected from 52 grid sampling locations in Cell E and 68 locations in Cell F. During each bioremediation progress measurement sampling event, approximately 50% of these locations were sampled. Sludge and subsoil samples were taken from the lagoon bottom using a core sampling device from a workboat. An OVM-PID meter was used to measure volatile organic concentrations along the surface of the core. The sludge sample was taken from the sludge layer at the point of highest volatile organic concentration. The subsoil sample was collected from a composite of the subsoil from the upper 4-foot layer of subsoil collected in each core. [9]

Tables 6 and 7 show the average concentrations measured in the subsoil and sludge during the bioremediation treatment of Cells E and F, respectively. The values shown on these tables are for composited samples collected during the treatment process.

The five indicator compounds showed reductions in concentrations over the course of treatment. For example, benzene was reduced from 608.0 mg/kg to 4.4 mg/kg in Cell E, and from 393.3 mg/kg to 5.2 mg/kg in Cell F. [13-20, 24-31]

Mixed liquor samples were collected at two locations in each treatment cell, and analyzed for the parameters listed in Table 8 to monitor the treatment performance. One sample was taken from the middle of the walkway across the sheetpile wall that separates the two treatment cells and a second sample was taken at the middle of treatment cell using the site workboat for access to the location. [9] The mixed liquor contained about 5-10% solids during operation. [38]

An ambient air monitoring program was implemented to monitor potential releases of VOCs from the bioremediation process. Ambient air monitoring was completed using automatic instrumentation equipment placed at strategic points around the operating bioremediation treatment cell. Table 9 shows total VOC concentrations, reported as maximum organic vapor analyzer (OVA) readings at various locations around the site boundary by month for January 1992 through August 1993. Total VOC concentrations ranged from 0.3 to 1.6 ppm, which were lower than the action level of 11 ppm specified in the ROD. [9]

Ambient air monitoring was also completed using continuous sampling at points between the bioremediation cell and the three nearest potential receptors. Samples were analyzed daily to provide a time-integrated measurement of 35 VOCs and to provide data, on a weekly basis, to calculate the health risk to the nearest receptors. As reported by FLTG, the health risk resulting from air emissions was within U.S. EPA-approved health risk criteria. [9]

## Performance Data Assessment

The treatment results, shown in Tables 6 and 7, indicate that the cleanup criteria were met within 10 months from the start of treatment for Cell E (October 1992) and 11 months for Cell F (November 1993). For individual constituents, cleanup goals were achieved the soonest for vinyl chloride (4 months in Cell E, 1 month in Cell F) and total PCBs (4 months in Cell E, 1 month in Cell F); benzo(a)pyrene required the longest amount of treatment time to meet the cleanup goals.

Concentrations were reduced to below detection limits in Cell E and 6.6 mg/kg in Cell F for vinyl chloride; 4.4 mg/kg in Cell E and 5.2 mg/kg in Cell F for benzene; and 6.0 mg/kg in Cell E and 6.8 mg/kg in Cell F for benzo(a)pyrene. In addition, the ambient air monitoring data show no exceedances of the established criteria for releases of VOCs. These data, in combination with the operating data, indicate that organic compounds, including vinyl chloride, benzene, and

## TREATMENT SYSTEM PERFORMANCE (CONT.)

*Table 6. Cell E Treatment Performance Data - Average Subsoil and Sludge Results [13-20]*

[redacted]

**Remediation began in January 1992.*
*BDL - Below Detection Limit (value in parentheses is detection limit)*
*NR - Not Reported.*

## TREATMENT SYSTEM PERFORMANCE (CONT.)

*Table 7. Cell F Treatment Performance Cata - Average Subsoil and Sludge Results [24-31]*

[redacted]

**Remediation began in January 1993.*

# TREATMENT SYSTEM PERFORMANCE (CONT.)

## Performance Data Assessment (cont.)

benzo(a)pyrene were removed from the lagoon via biodegradation. According to the FLTG, available data indicate that PCBs were biodegraded in the slurry-phase system to concentrations below the action levels established for French Ltd. Also, according to the FLTG, arsenic and metals were not biodegraded; they were dispersed in the final residue. [38]

*Table 9. Total VOC Readings by Month [37]*

| Month | Total VOC* (ppm) |
|---|---|
| January 1992 | 1 |
| February 1992 | 0.9 |
| March 1992 | 0.9 |
| April 1992 | 1.1 |
| May 1992 | 1.1 |
| June 1992 | 1.3 |
| July 1992 | 1 |
| August 1992 | 0.8 |
| September 1992 | 0.9 |
| October 1992 | 0.6 |
| November 1992 | 1.6 |
| December 1992 | 0.4 |
| January 1993 | 0.5 |
| February 1993 | 0.4 |
| March 1993 | 0.6 |
| April 1993 | 0.5 |
| May 1993 | 0.6 |
| June 1993 | 0.5 |
| July 1993 | 0.4 |
| August 1993 | 0.3 |

*Total VOC concentrations as maximum OVA readings.*

## Performance Data Completeness

The available data characterize the concentration of five contaminants in the subsoil and sludge over the course of the bioremediation, as well as three potential indicator parameters (TPH, % solids, and % volatile solids). Data are not available to match these treated concentrations with concentrations in the cells before treatment. The first samples taken after mixing began were at Day 96 for Cell E and Day 38 for Cell F.

## TREATMENT SYSTEM PERFORMANCE (CONT.)

### Performance Data Quality

Quality assurance/quality control (QA/QC) procedures for sampling and analytical activities are outlined in the second volume of the Remedial Action Plan, entitled Quality Assurance Plan. Monthly progress reports prepared by the FLTG include discussions of QA/QC issues during the remediation. EPA took split samples of confirmation samples after the cleanup objectives had been met. According to monthly progress reports, there were no discrepancies between the samples taken by FLTG and EPA.

## TREATMENT SYSTEM COST

### Procurement Process [38, 39]

FLTG contracted with ENSR to design the slurry-phase bioremediation system, and with Bechtel Corporation to construct the lagoon remediation system. FLTG and ENSR selected several key equipment vendors by competitive bidding, including Praxair, Dredging Supply, ITT Flygt, Sala, and Siemens. FLTG directly hired personnel and support staff to operate and maintain the remediation systems.

All contracts were competitively bid. Contracts were awarded based on commercial terms and qualifications. Contract types included lump sum, fixed unit price, and cost reimbursable depending on the scale of work and degree of definition.

### Treatment System Cost

According to the FLTG, the total cost of remediating the soil and sludge in the lagoon at French Ltd. was $49,000,000, including costs for technology development, project management, EPA oversight, and backfill of the lagoon. The $49,000,000 total cost was broken down into nine project elements by the RPM and FLTG, as shown in Table 10. [37, 39]

The FLTG also provided a breakdown of the costs according to the format for an interagency Work Breakdown Structure (WBS), as shown in Tables 11, 12, and 13. The WBS is being used as a format for standardizing reporting of costs across projects. No additional information on the specific items included in each cost element shown in Tables 11, 12, and 13 were provided by the FLTG. [38]

As shown in Tables 11, 12, and 13, approximately 55% of the project costs were for activities directly associated with treatment, 34% were for before-treatment activities, and 11% for after-treatment activities. The $26,900,000 in costs for activities directly associated with treatment corresponds to approximately $90/ton of sludge and soil treated (for 300,000 tons treated).

*Table 10. Breakdown of Project Costs by the RPM and FLTG [37, 39]*

| Project-Element | Cost ($) |
|---|---|
| Development and Pilot-Scale Work | 12,200,000 |
| Floodwall | 2,300,000 |
| Operation, Maintenance, Analytical | 22,900,000 |
| Dewatering | 1,000,000 |
| Fixation | 400,000 |
| Technical Support | 2,900,000 |
| Administrative | 3,100,000 |
| Demobilization | 1,900,000 |
| EPA Oversight | 2,300,000 |
| Total | 49,000,000 |

# TREATMENT SYSTEM COST (CONT.)

## Treatment System Cost (cont.)

*Table 11. Treatment Activity Cost Elements Provided by FLTG According to the WBS [38]*

| Cost Elements (Directly Associated With Treatment) | Cost (dollars) | Actual or Estimated (A) or (E) |
|---|---|---|
| Solids Preparation and Handling | 2,200,000 | A |
| Liquid Preparation and Handling | 2,800,000 | A |
| Vapor/Gas Preparation and Handling | 4,600,000 | A |
| Pads/Foundation/Spill Control | 300,000 | A |
| Mobilization/Set Up | 1,200,000 | A |
| Startup/Testing/Permits | 1,300,000 | A |
| Training | 900,000 | A |
| Operation (short-term - up to 3 years) | 13,600,000 | A |
| TOTAL TREATMENT ACTIVITY COST | 26,900,000 | A |

*Table 12. Before-Treatment Cost Elements Provided by FLTG According to the WBS [38]*

| Cost Elements | Cost (dollars) | Actual or Estimated (A) or (E) |
|---|---|---|
| Mobilization and Preparatory Work | 1,100,000 | A |
| Monitoring, Sampling, Testing, and Analysis | 4,900,000 | A |
| Site Work | 4,000,000 | A |
| Surface Water Collection and Control | 2,300,000 | A |
| Groundwater Collection and Control | 1,100,000 | A |
| Air Pollution/Gas Collection and Control | 1,800,000 | A |
| Solids Collection and Containment | 600,000 | A |
| Liquids/Sediments/Sludges Collection and Containment | 800,000 | A |
| Drums/Tanks/Structures/Miscellaneous Demolition and Removal | 200,000 | A |
| TOTAL BEFORE-TREATMENT COST | 16,800,000 | A |

*Table 13. After-Treatment Cost Elements Provided by FLTG According to the WBS [38]*

| Cost Elements | Cost (dollars) | Actual or Estimated (A) or (E) |
|---|---|---|
| Decontamination and Decommissioning | 1,300,000 | A |
| Disposal (other than commercial) | 400,000 | A |
| Disposal (commercial) | 400,000 | A |
| Site Restoration | 2,300,000 | A |
| Demobilization (other than treatment unit) | 400,000 | A |
| Other (topsoil and revegetation) | 800,000 | A |
| TOTAL AFTER-TREATMENT COST | 5,600,000 | A |

# TREATMENT SYSTEM COST (CONT.)

## Cost Data Quality

The cost information presented above represents actual costs for this application. Cost information was available for activities directly associated with treatment, and for elements associated with before-treatment and after-treatment activities.

## PRP and Vendor Input [38-40]

According to the FLTG, the costs for future, similar applications are expected to be similar to those incurred for French Ltd., and depend on site-specific chemical and physical conditions. The key factors which affect costs of bioremediation systems are oxygen and nutrient supply.

According to ENSR, costs for a second generation system that did not require pilot studies or sheet pile work would be about 40% less than those incurred at French Ltd.

According to Praxair, the cost of oxygen at future similar sites will be affected by the location of the site (local power rates affect oxygen production costs), the distance from the oxygen-producing plant (distribution costs), the rate of oxygen consumption (site supply system requirements), and the duration of the oxygen use (amortization of installation/removal costs).

The cost of the MixFlo system will be affected by the rate of oxygen dissolution (capital and operating costs) and the oxygen dissolution characteristics of the slurry.

As a result of the application at the French Ltd. site, Praxair, Inc. has developed a new oxygen dissolution technology—the In-Situ Oxygenator™. This system dissolves oxygen and suspends solids using approximately 25% of the power required by MixFlo or by air-based aeration systems while maintaining the high-oxygen utilization efficiency of the MixFlo technology.

# OBSERVATIONS AND LESSONS LEARNED

## Cost Observations and Lessons Learned

- Treatment costs, including project management, pilot studies, technology development, EPA oversight, and backfill of the lagoon, were approximately $49,000,000.
- Fifty-five percent of the costs ($26,900,000) were for activities directly associated with treatment, such as solids preparation and handling, liquid preparation and handling, vapor/gas preparation and handling, pads/foundations/spill control, mobilization/set up, startup/testing/ permits, training, and operation (short-term - up to 3 years).
- The $26,900,000 in costs for activities directly associated with treatment corresponds to approximately $90/ton of sludge and soil treated (for 300,000 tons treated).
- Excavation was not required for treatment at French Ltd., and the relatively large quantity of sludge and soil treated at this site resulted in economies-of-scale.

## Performance Observations and Lessons Learned

- Performance data indicated that the cleanup goals for the five target compounds (benzo(a)pyrene, PCBs, vinyl chloride, arsenic, and benzene) were met within 10 months for treatment of one cell and 11 months for the other cell.

## OBSERVATIONS AND LESSONS LEARNED (CONT.)

### Performance Observations and Lessons Learned (cont.)

- Operations data show that vinyl chloride, benzene, and benzo(a)pyrene were biodegraded in this application. Concentrations were reduced to below detection limits in Cell E and 6.6 mg/kg in Cell F for vinyl chloride; 4.4 mg/kg in Cell E and 5.2 mg/kg in Cell F for benzene; and 6.0 mg/kg in Cell E and 6.8 mg/kg in Cell F for benzo(a)pyrene.
- Air emission limits were not exceeded during this application.
- The MixFlo system maintained a dissolved oxygen level in the slurry of 2.0 mg/L, mixed the slurry, and minimized air emissions.

### Other Observations and Lessons Learned

- The treatability study predicted removal of volatile organic compounds and polynuclear aromatic hydrocarbons during sludge and soil mixing, and extended aeration within 275 project days. Full-scale treatment performance data indicated that the cleanup goals for the indicator compounds were met within this time period.
- The treatability study demonstrated the feasibility of bioremediation for VOCs and SVOCs in soil and sludge within the lagoon without exceeding air emissions limitations.

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# ACKNOWLEDGMENTS


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# APPENDIX A - TREATABILITY STUDY RESULTS

| | |
|---|---|
| **Identifying Information** | |
| French Limited Superfund Site<br>Crosby, Texas | CERCLIS#: TXD980514814<br>ROD Date: 24 March 1988 |
| Historical Activity at Site - SIC Codes: | 4953 (Waste Management-refuse systems; sand and gravel pit disposal) |
| Historical Activity at Site - Management Practices: | Disposal Pit |
| Site Contaminants: | Polynuclear aromatic hydrocarbons: halogenated semivolatiles; non-halogenated volatiles: metals; and nonmetallic elements |
| Type of Action: | Remedial |
| Did the ROD/Action Memorandum include a contingency on treatability study results? | No |
| **Treatability Study Information** | |
| Type of Treatability Study: | Pilot |
| Duration of Treatability Study: | April 1987 to April 1988 |
| Media Treated: | Soil and Sludge (in situ) |
| Quantity Treated: | 0.5-acre cell |
| Treatment Technology: | Slurry-Phase Bioremediation |
| Target Contaminants of Concern: | Volatile Organic Compounds (VOCs) and Semivolatile Organic Compounds (SVOCs) |
| Conducted before the ROD was signed: | Yes |
| Additional treatability studies conducted: | Yes (laboratory/bench-scale and tank-scale studies of bioremediation also conducted) |
| Technology selected for full-scale application: | Yes |
| **Treatability Study Strategy** | |
| Key Operating Parameters Varied: | Different aerators and mixers were used |
| **Treatability Study Results** | |
| Range of Individual VOC Concentrations in Untreated Soil and Sludge Matrix: | Up to 3,500 mg/kg |
| Range of Individual SVOC Concentrations in Untreated Soil and Sludge Matrix: | Up to 6,000 mg/kg |
| Range of Treated VOC Concentrations in Soil and Sludge Matrix: | Less than 100 mg/kg |
| Range of Treated SVOC Concentrations in Soil and Sludge Matrix: | Less than 100 mg/kg |
| **Site Logistics/Contact Information:** | |
| French Ltd. Task Group | Mr. R.L. (Dick) Sloan<br>Project Coordinator<br>FLTG, Incorporated<br>15010 FM 2100, Suite 200<br>Crosby, Texas 77532<br>(713) 328-3541 |



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Technology Innovation Office

# APPENDIX A - TREATABILITY STUDY RESULTS (CONT.)

## IDENTIFYING INFORMATION

**Type of Treatability Study:** Pilot-scale slurry-phase bioremediation study of sludge and subsoil contaminated with PCBs, benzo(a)pyrene, benzene, vinyl chloride, arsenic, and other VOCs and SVOCs.

## TREATABILITY STUDY STRATEGY [8]

**Treatability Study Purpose:** The purpose of the pilot-scale treatability study was to assess the feasibility of bioremediation of the contaminated lagoon at the site, and to determine the following:

- Whether indigenous microorganisms could be stimulated to destroy the organic waste materials and clean up contaminated soil in a reasonable amount of time;
- How to control air emissions during remediation;
- How to mechanically mix the microorganisms, oxygen, nutrients, and mixed liquor to obtain satisfactory reaction rates; and
- How long the cleanup would take.

**Cleanup Goals/Standards:** Cleanup goals were not identified for the French Ltd. site at the time of the pilot-scale treatability study.

## TREATMENT SYSTEM DESCRIPTION [8]

**Treatment System Description and Operation:** Earlier tests were performed from late 1986 to early 1987 using two 20,000-gallon reactors to determine if microorganisms could be stimulated to degrade site contaminants in a reasonable amount of time.

Subsequently, a pilot-scale test was operated on a one-half acre cell on the west end of the lagoon between April 1987 through April 1988. The equipment included ambient air control, sparged air aeration, and mixers.

The study included the following operation:

- Aeration of the mixed liquor;
- Nutrient addition to grow the biomass; and
- Shearing of sludges and contaminated soil.

The sludge and soil were sheared so that the contaminants would be brought into contact with the microbes. A swinging-ladder dredge was used to shear the soil and open-faced centrifugal pumps were used for the tarry sludge. Over the course of the pilot test, many different aerators, mixers, and dredges were tested. [8]

**Procurement Process/Treatability Study Cost:** The cost of the pilot-scale treatability test was $5 million.

## TREATABILITY STUDY RESULTS [8]

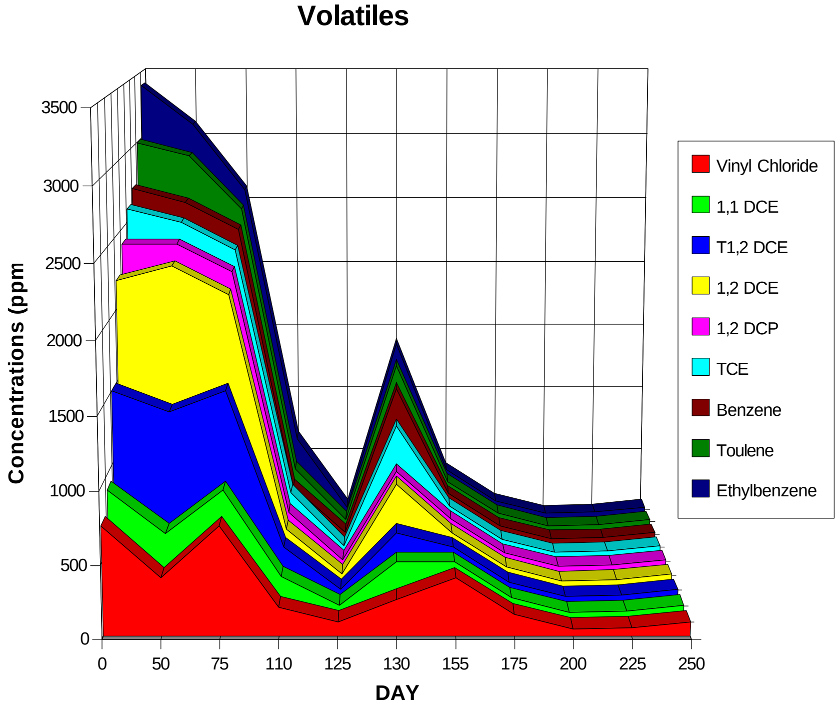
**Operating Parameters and Performance Data**: The initial reactor tests showed that the native microorganisms could be successfully stimulated to metabolize the organic waste materials in a reasonable amount of time.

The results of the pilot test showed a reduction in concentration of volatile organic compounds (VOCs) and semi-volatile compounds (SVOCs), as shown in Figure A-1, during the course of the study.

**Performance Data Assessment:** The results in Figure A-1 show a reduction in concentration of 9 VOCs and 9 SVOCs to concentrations of less than 100 mg/kg for individual VOCs and SVOCs, and that bioremediation is

## APPENDIX A: TREATABILITY STUDY RESULTS (CONT.)

**Reduction in volatile organic concentrations in main waste lagoon using bioremediation**




**Reductions in semivolatile organic compound concentrations in main waste lagoon using bioremediation**

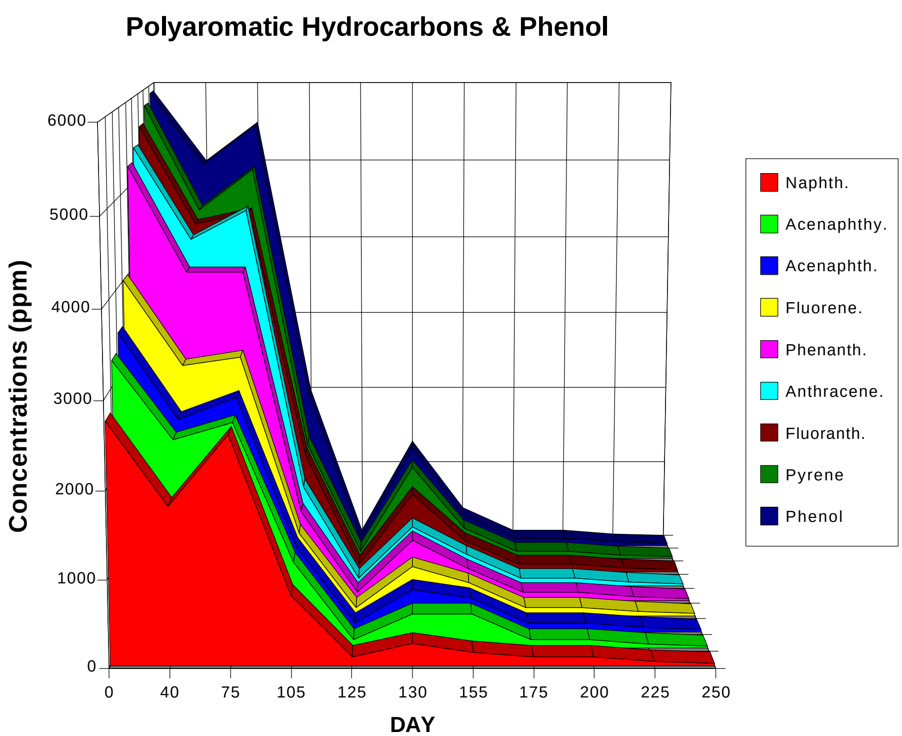



*Figure A-1. Reductions in VOC and SVOC Concentrations During Pilot Test [8]*

# APPENDIX A- TREATABILITY STUDY RESULTS (CONT.)

## TREATABILITY STUDY RESULTS (cont.) [8]

a feasible technology for remediation of the soil and sludge in the lagoon. The data indicate that removal of these contaminants occurred within 275 days of soil and sludge mixing and dredging, and extended aeration.

Although no data are available at this time, the results of the pilot test were used in selecting specific equipment and in optimizing operational methods for the full-scale remediation, including control of air emissions and performing mechanical mixing. The shearing equipment chosen allowed two different implements to be attached, one for shearing sludge and the other for shearing soil.

## OBSERVATIONS AND LESSONS LEARNED

- The initial reactor tests showed that the native microorganisms could be successfully stimulated to metabolize organic waste materials in a reasonable amount of time.
- The treatability study showed reductions in the concentrations of 9 VOCs and 9 SVOCs from soil and sludge in the lagoon to concentrations less than 100 mg/kg for individual contaminants. These results were achieved within 275 days of sludge and soil mixing and extended aeration.

# COST AND PERFORMANCE REPORT

**Slurry-Phase Bioremediation**
**at the**
**French Limited Superfund Site**
**Crosby, Texas**


*Prepared By:*

*U.S. Environmental Protection Agency*
*Office of Solid Waste and Emergency Response*
*Technology Innovation Office*


**March 1995**

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